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(54) **POWER GENERATOR, SECONDARY CELL, ELECTRONIC APPARATUS, AND TRANSPORTER**

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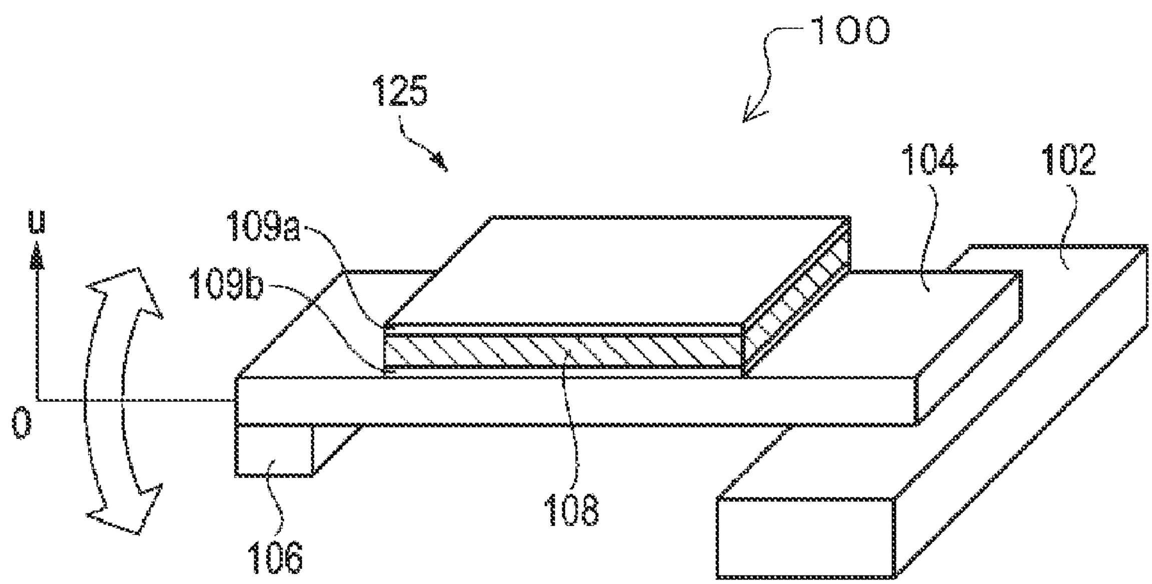
(57) **ABSTRACT**

A power generator includes a deforming unit that deforms a piezoelectric member, a pair of electrodes provided on the piezoelectric member, an inductor provided between the pair of electrodes and forming a resonator circuit with a capacity component of the piezoelectric member, a first switch connected in series with respect to the inductor, a unit that detects times when a deformation direction of the deforming unit is switched, a full-wave rectifier circuit that rectifies a current output from the pair of electrodes, an electrical storage device connected to the full-wave rectifier circuit and charging a current supplied from the full-wave rectifier circuit, a second switch connected between one of the pair of electrodes and the electrical storage device, and a control circuit that operates the first switch and the second switch.



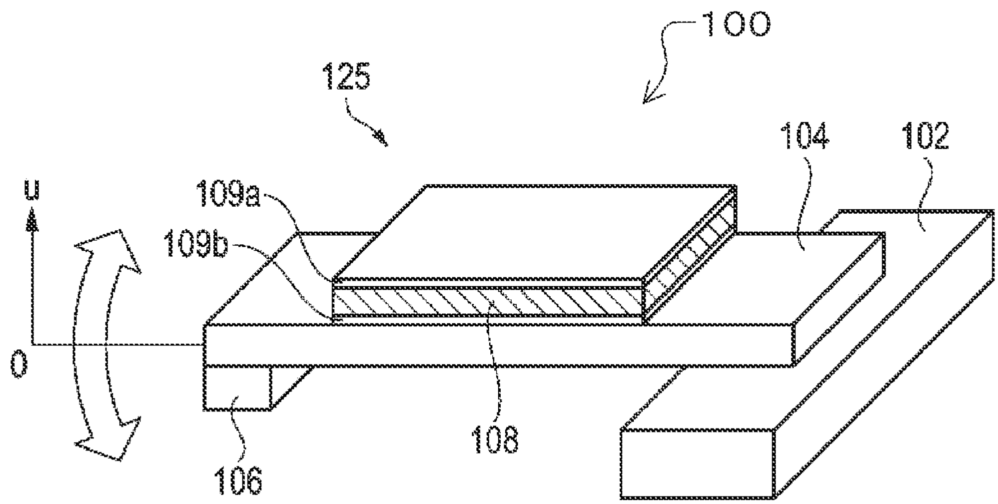
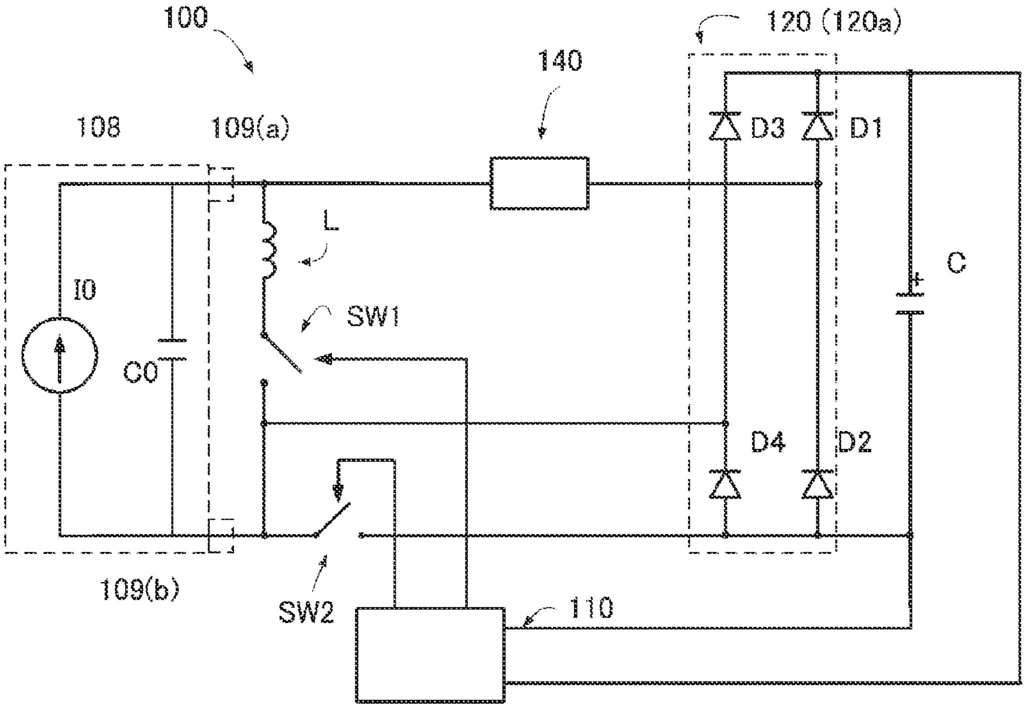


FIG. 1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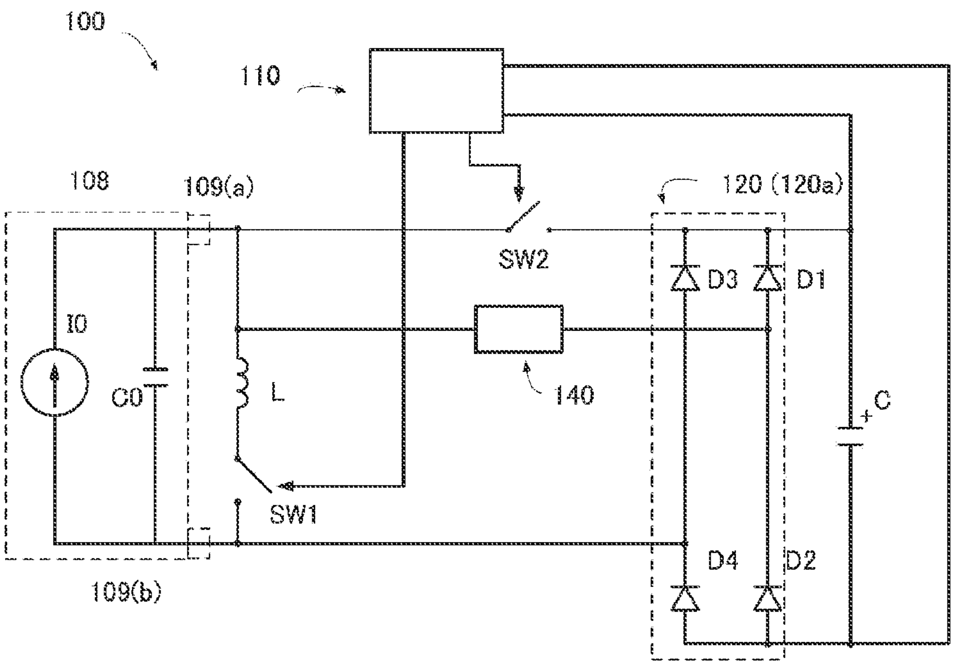
120 (120a)
140
108
109(a)
D3
D1
L
I0
SW1
C
C0
D4
D2
109(b)
SW2
110

FIG. 2A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110
108
109(a)
120 (120a)
SW2
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I0
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L
C
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D2
109(b)

FIG. 2B

FIG. 3A

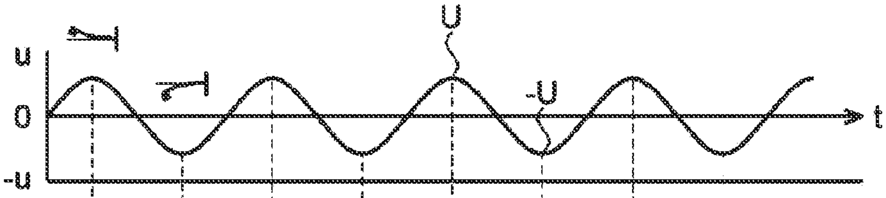


FIG. 3B

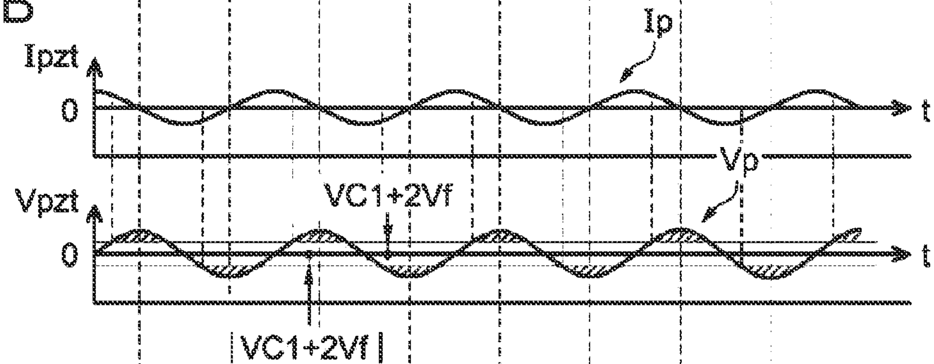


FIG. 3C

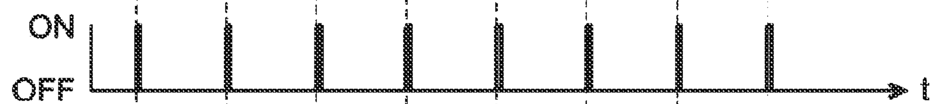
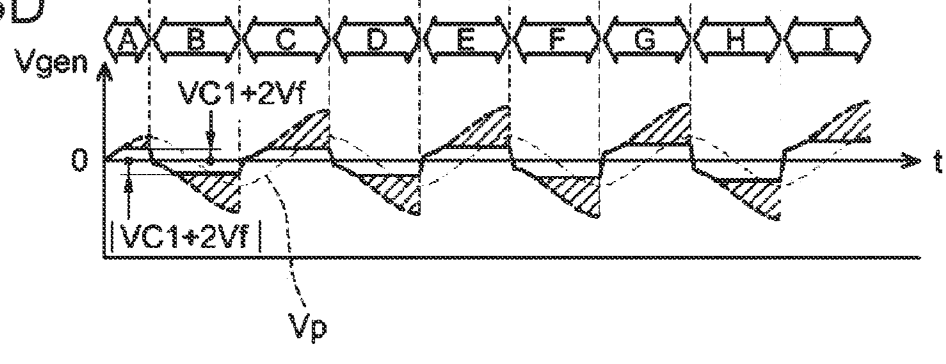
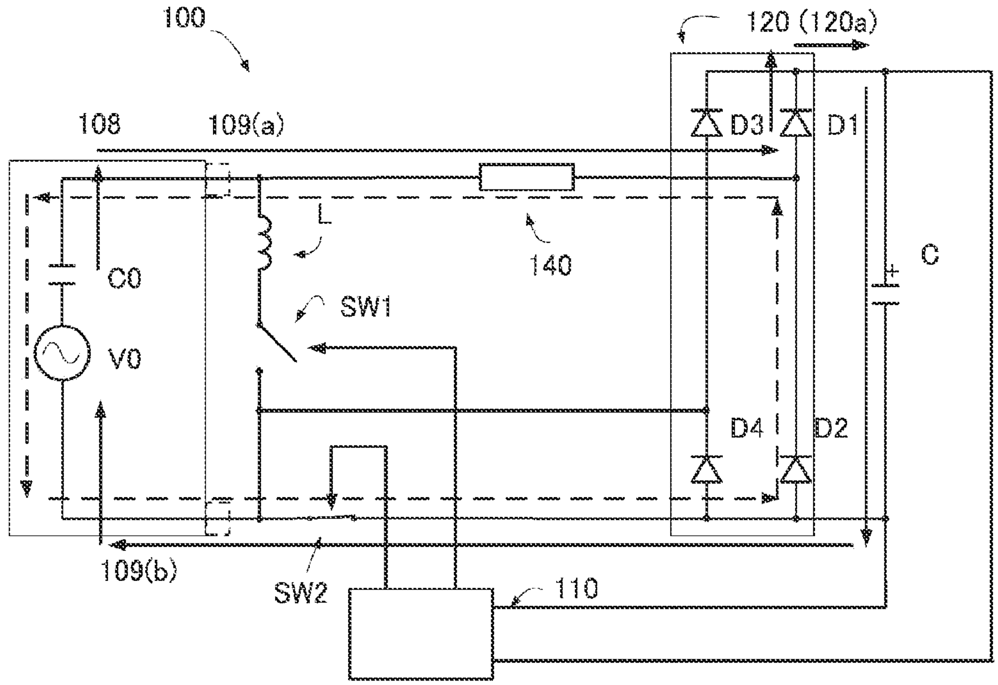


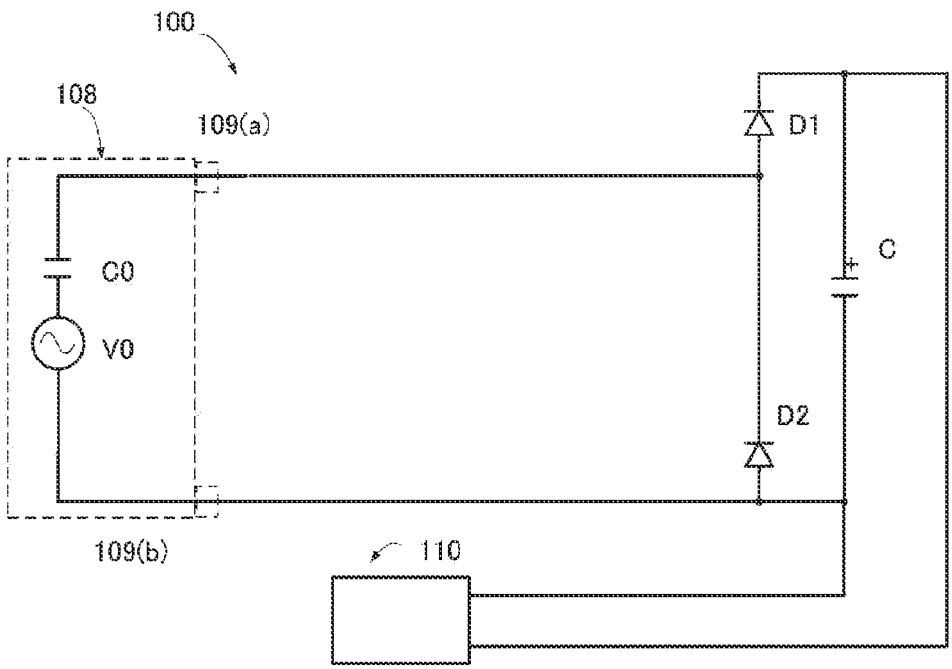
FIG. 3D





100
120 (120a)
108
109(a)
D3
D1
L
140
C
C0
SW1
V0
D4
D2
109(b)
SW2
110

FIG. 4A



100
108
109(a)
D1
C0
C
V0
D2
109(b)
110

FIG. 4B

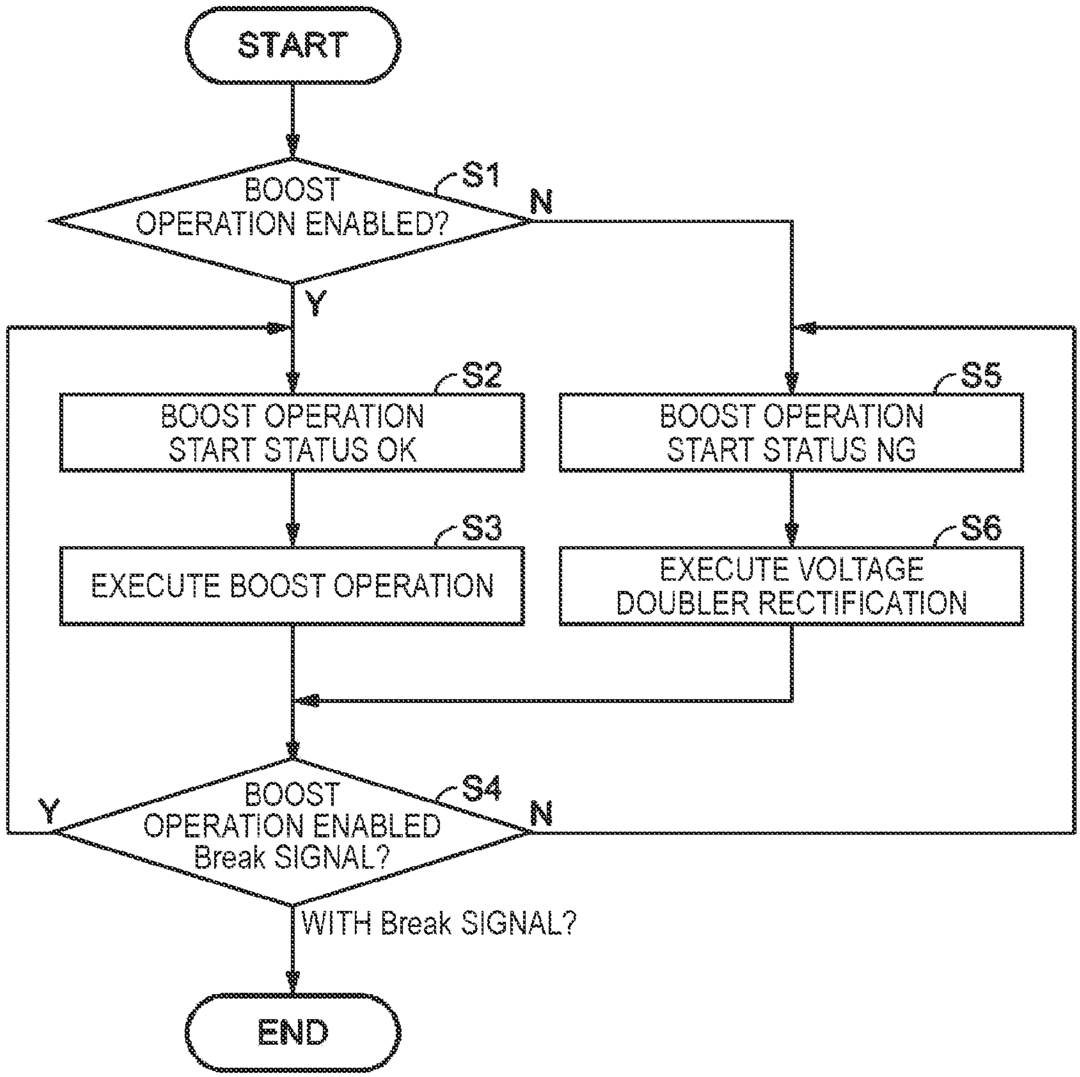
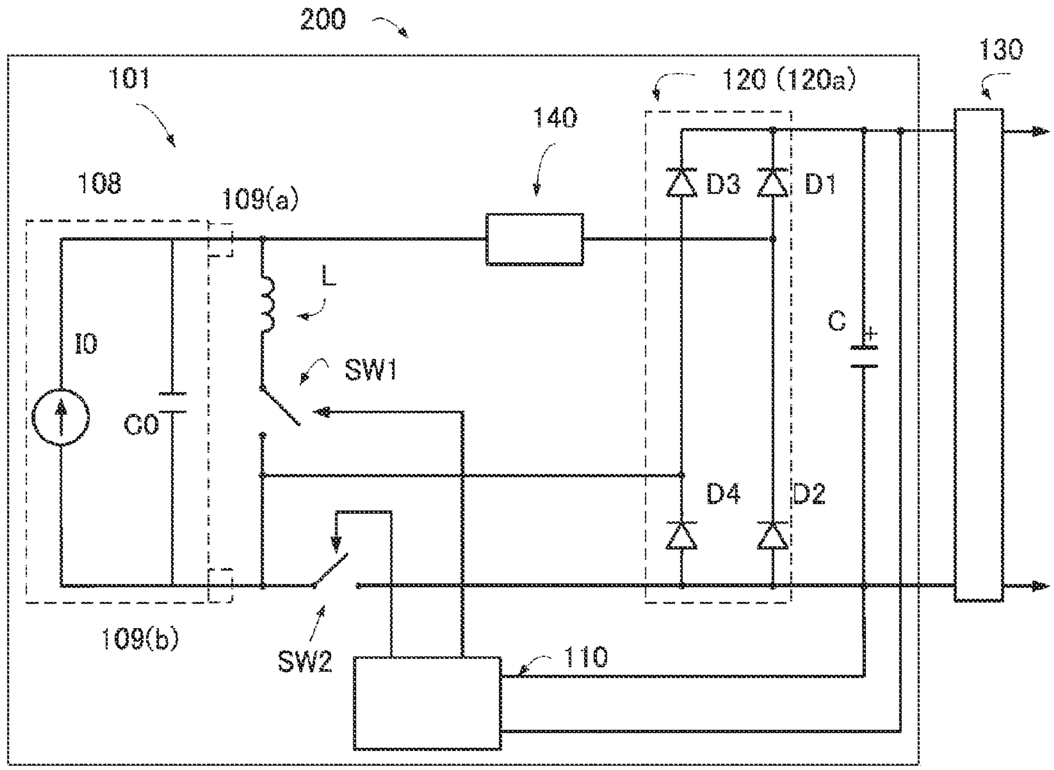

START
BOOST OPERATION ENABLED?
S1
N
Y
S2
BOOST OPERATION START STATUS OK
S5
BOOST OPERATION START STATUS NG
S3
EXECUTE BOOST OPERATION
S6
EXECUTE VOLTAGE DOUBLER RECTIFICATION
S4
BOOST OPERATION ENABLED Break SIGNAL?
Y
N
WITH Break SIGNAL?
END

FIG. 5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140
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C
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SW2
110

FIG. 6

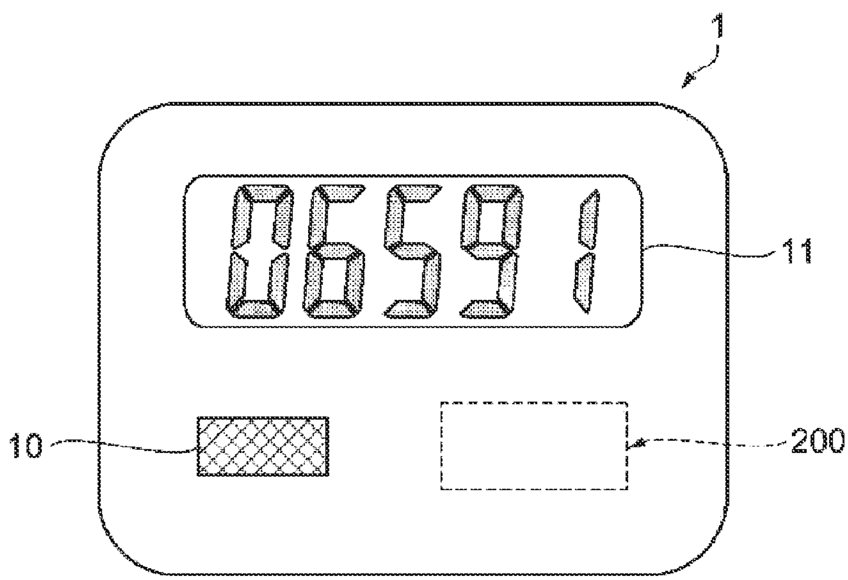
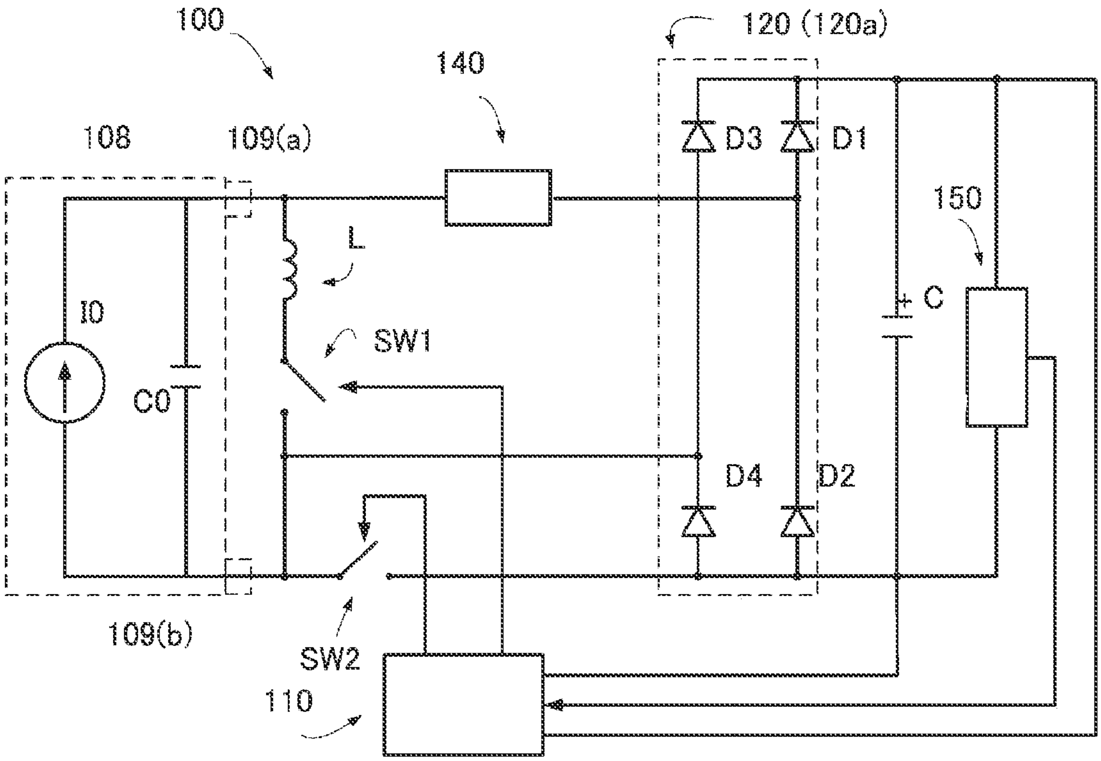

1
06591
11
10
200

FIG. 7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L
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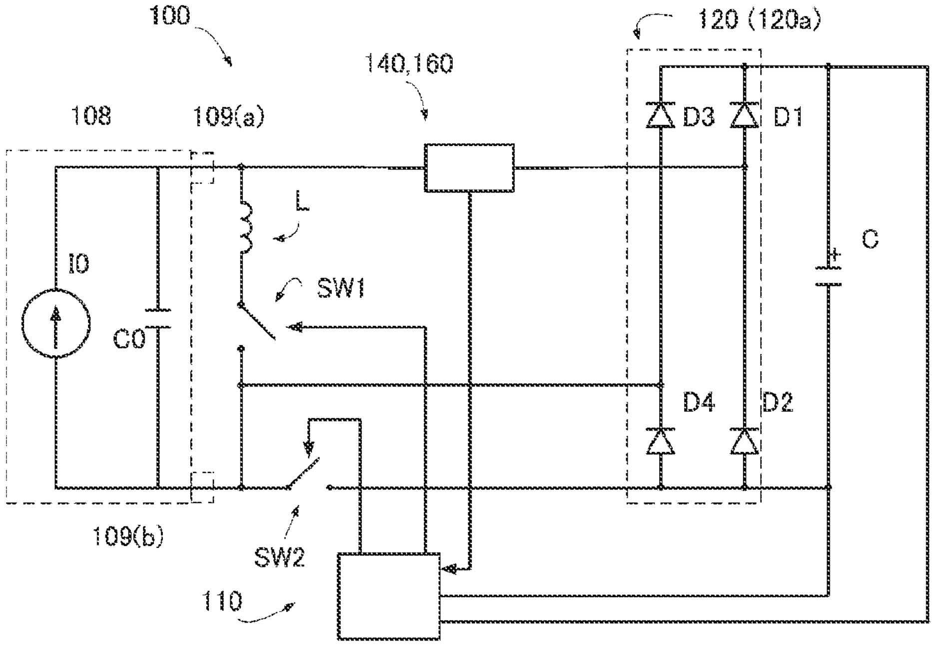
C
SW1
C0
D4
D2
109(b)
SW2
110

FIG. 8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109(a)
D3
D1
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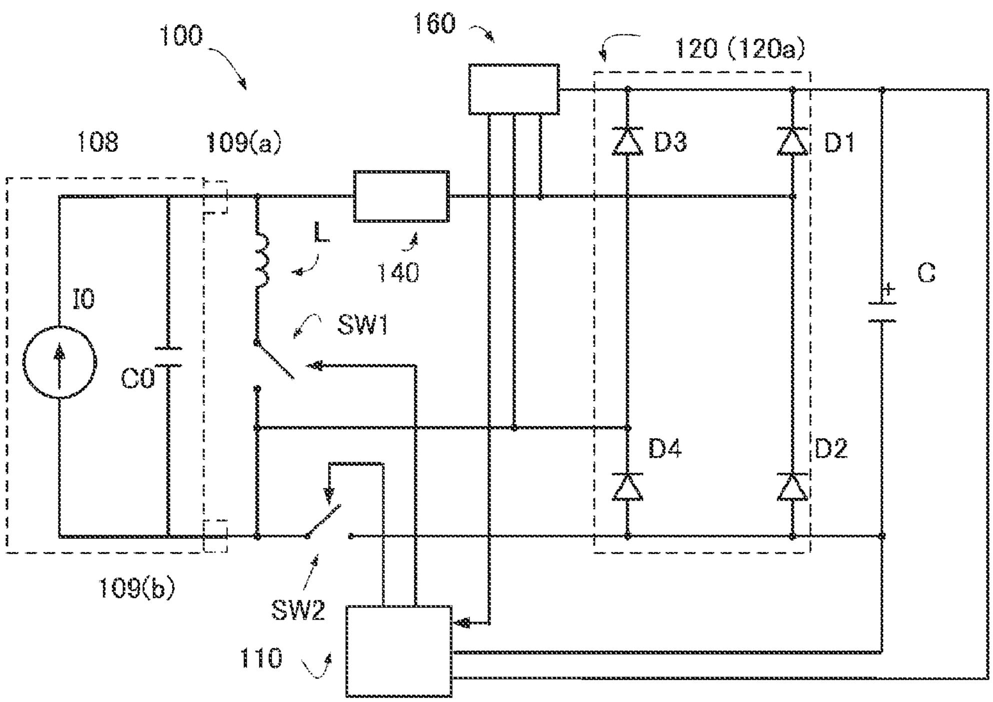
I0
C
SW1
C0
D4
D2
109(b)
SW2
110

FIG. 9A


100
160
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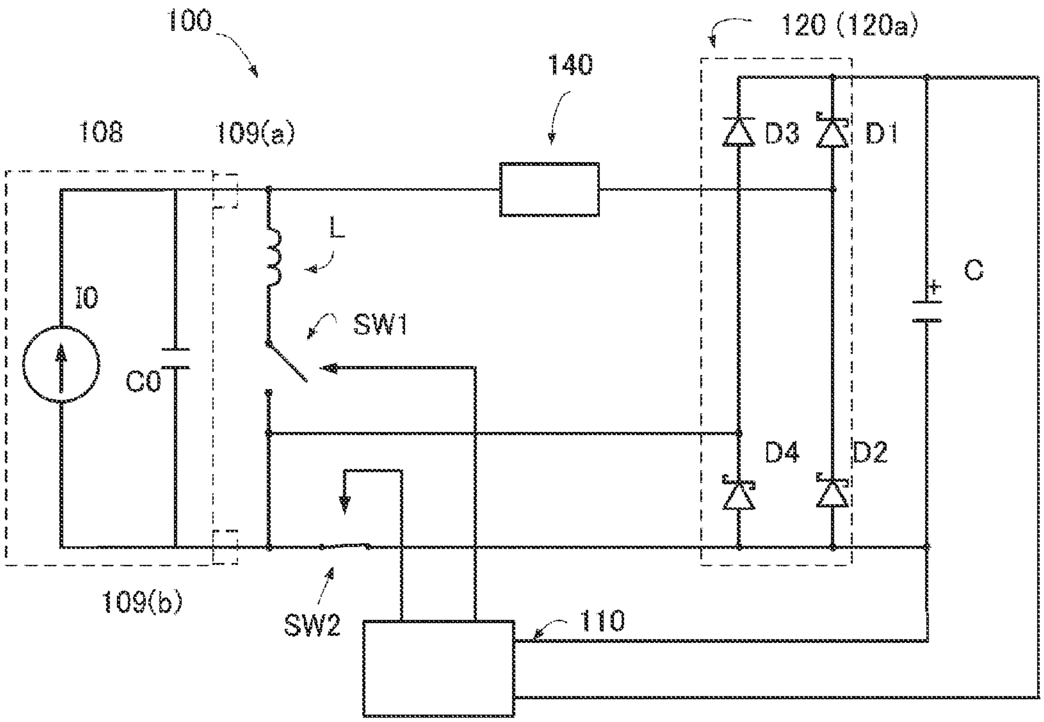
108
109(a)
D3
D1
L
140
I0
C
SW1
C0
D4
D2
109(b)
SW2
110

FIG. 9B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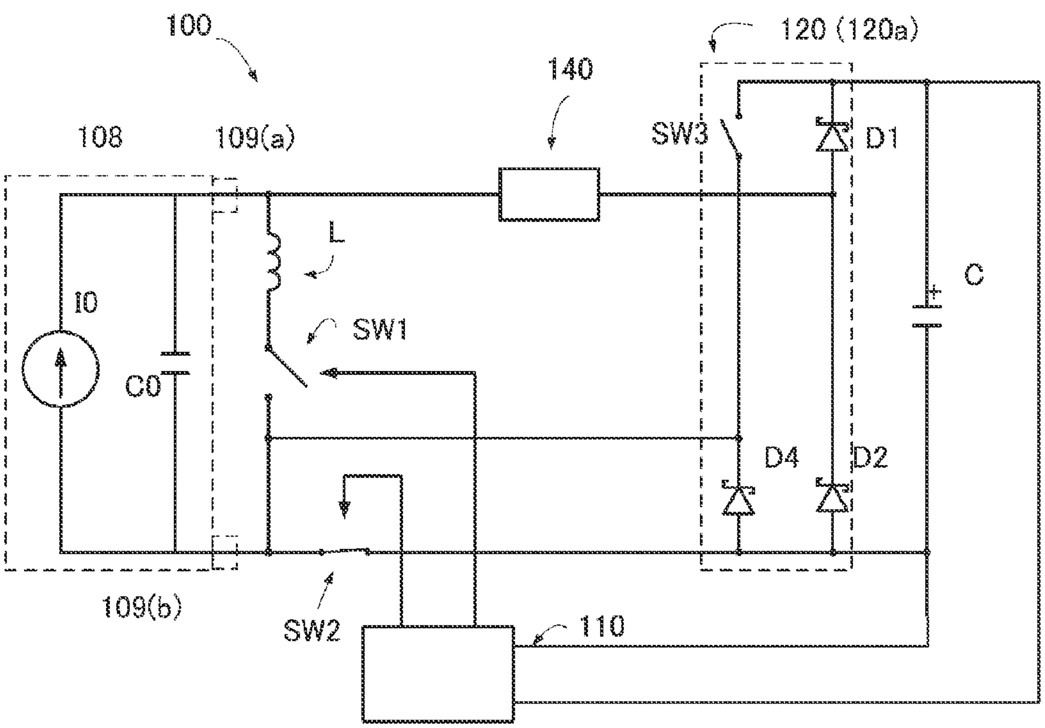
D3
D1
L
I0
C
SW1
C0
D4
D2
109(b)
SW2
110

FIG.10


100
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140
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109(a)
SW3
D1
L
I0
C
SW1
C0
D4
D2
109(b)
SW2
110

FIG.11

POWER GENERATOR, SECONDARY CELL, ELECTRONIC APPARATUS, AND TRANSPORTER

BACKGROUND

[0001] 1. Technical Field

[0002] The present invention relates to a power generator, a secondary cell, an electronic apparatus, and a transporter.

[0003] 2. Related Art

[0004] When piezoelectric materials including lead zirconate titanate (PZT), quartz (SiO_2), and zinc oxide (ZnO) are subjected to external force and deformed, electric polarization is induced within the materials and positive and negative electric charge appears on the surfaces. The phenomenon is called piezoelectric effect. Using the property of the piezoelectric material, a power generation method of vibrating a cantilever so that load may repeatedly act on the piezoelectric material and extracting the electric charge generated on the surface of the piezoelectric material as a current has been proposed.

[0005] For example, a metal cantilever with a weight and a thin plate of a piezoelectric material attached to its end is vibrated and positive and negative electric charge alternately generated in the piezoelectric material with the vibration is extracted, and thereby, an alternating current is generated. Further, a technology of rectifying the alternating current using a diode, then, accumulating it in a capacitor, and extracting it as power has been proposed (for example, see Patent Document 1 (JP-A-7-107752)). Furthermore, a technology of obtaining a direct current without generation of voltage loss in a diode by closing a contact point only while positive electric charge is generated in the piezoelectric material has been proposed (for example, see Patent Document 2 (JP-A-2005-312269)). A power generator may be downsized using these technologies. Accordingly, for example, application of incorporation of the power generator into a small electronic part in place of a battery or the like is expected.

[0006] However, in the proposed power generators in related art, there has been a problem that the obtained voltage is restricted up to a voltage generated by electric polarization of the piezoelectric material. Accordingly, in most cases, there has been an issue that a separate booster circuit is necessary and sufficient downsizing of the power generator is difficult. Further, to drive the booster circuit, power to drive the booster circuit is necessary, however, there has been an issue that boost operation becomes difficult when electrical energy of an electrical storage device is lower. In order to solve the issues, there is a method of providing a full-wave rectifier circuit or a voltage doubler rectifier circuit in parallel to the booster circuit, however, there has been an accompanying issue of upsizing of the power generator.

SUMMARY

[0007] An advantage of some aspects of the invention is to solve at least a part of the problems described above and the invention can be implemented as the following embodiments or application examples.

Application Example 1

[0008] This application example is directed to a power generator that generates power using power generated in a piezoelectric member when the piezoelectric member is deformed, including a deforming unit that repeatedly deforms the piezoelectric member, a pair of electrodes provided on the piezoelectric member, an inductor provided between the pair of electrodes and forming a resonator circuit with a capacity component of the piezoelectric member, a first switch connected in series with respect to the inductor, a unit that detects times when a deformation direction of the deforming unit is switched, a full-wave rectifier circuit that rectifies a current output from the pair of electrodes, an electrical storage device connected to the full-wave rectifier circuit and charging the current supplied from the full-wave rectifier circuit, a second switch connected between one of the pair of electrodes and the electrical storage device, and a control circuit that operates the first switch and the second switch.

[0009] According to the configuration, the piezoelectric member is repeatedly deformed by switching the deformation direction in response to external force, and thereby, positive and negative electric charge is generated by the piezoelectric effect in the piezoelectric member. When the first switch is short-circuited and the piezoelectric member is connected to the inductor, the piezoelectric member may be regarded as a capacitor in an electric circuit, and a resonator circuit is formed by connection to the inductor. Then, the electric charge generated in the piezoelectric member flows into the inductor. The piezoelectric member and the inductor form the resonator circuit, and the current flowing into the inductor overshoots and flows into the piezoelectric member from the opposite terminal. Thereby, the arrangement of the positive and negative electric charge generated within the piezoelectric member may be inversed before connection to the inductor.

[0010] Further, from the state, in turn, the piezoelectric member is deformed in the opposite direction, and the electric charge generated by the piezoelectric effect is accumulated in addition to the electric charge inverted and accumulated. As a result, the electric charge generated by repeated deformation of the piezoelectric member may be accumulated within the piezoelectric member. Furthermore, the voltage between terminals also increases by the amount of electric charge accumulated within the piezoelectric member, and thus, even if a booster circuit is not separately prepared, a higher voltage than the voltage generated by electric polarization of the piezoelectric material may be generated. As a result, the small and highly-efficient power generator may be obtained.

[0011] Here, to perform the boost operation, it is necessary to actively control the first switch that connects/opens the piezoelectric member and the inductor. That is, if the voltage provided to the control circuit is once below the lower limit voltage necessary for driving the first switch, it becomes impossible to actively control the first switch, and rectification is performed by the full-wave rectifier circuit for charging without the above described boost operation.

[0012] In the case where rectification is performed by the full-wave rectifier circuit for charging, it is difficult to supply the voltage equal to or more than the lower limit voltage necessary for driving the first switch to the control circuit because the voltage that may be charged in the electrical storage device is low. Accordingly, in this case, the control circuit short-circuits the second switch and switches to the voltage doubler rectifier circuit using the capacity component of the piezoelectric member. Thereby, the voltage nearly double that of the full-wave rectifier circuit may be charged in the electrical storage device, and the voltage applied to the control circuit exceeds the lower limit voltage necessary for driving the first switch. Therefore, self-resetting to the boost operation may be performed. Further, the voltage doubler rectification is performed using the capacity component of the piezoelectric member, and thereby, the small and low-cost power generator may be provided without the need of extra parts.

Application Example 2

[0013] This application example is directed to the power generator according to the application example described above, wherein the control circuit disconnects the second switch and short-circuits the first switch when a voltage charged in the electrical storage device reaches a voltage that can drive the first switch.

[0014] According to the configuration, when the voltage charged in the electrical storage device reaches the voltage that can drive the first switch, the second switch is disconnected and the first switch is short-circuited, and thereby, the voltage nearly double that of the full-wave rectifier circuit may be charged in the electrical storage device. Accordingly, the voltage applied to the control circuit exceeds the lower limit voltage necessary for driving the second switch, and self-resetting to the boost operation may be performed. Further, the voltage doubler rectification is performed using the capacity component of the piezoelectric member, and thereby, the small and low-cost power generator may be provided without the need of extra parts.

Application Example 3

[0015] This application example is directed to the power generator according to the application example described above, wherein the control circuit performs control of disconnecting the second switch and short-circuiting the first switch at the time when the deformation direction of the deforming unit is switched and, after a lapse of a time corresponding to a half-cycle of a resonance cycle of the resonator circuit, disconnecting the first switch when a voltage charged in the electrical storage device reaches a voltage that can drive the first switch and the second switch.

[0016] According to the configuration, when the first switch is operated and the boost operation is performed, the second switch is disconnected and the circuit is operated as the full-wave rectifier circuit, and thereby, the boost operation may be efficiently performed. Further, the amount of generated electric charge is larger as the amount of deformation of the piezoelectric member is larger, and thus, when the electric charge accumulated in the piezoelectric member is the maximum, the positive and negative electric charge within the piezoelectric member may be inversed by short-circuiting of the first switch when the deformation direction is switched. The time in which the first switch is short-circuited is a time taken for inversion of the electric charge of the piezoelectric member, and, if the first switch is short-circuited in the time corresponding to the half of the resonance cycle of the resonator circuit formed by the piezoelectric member and the inductor, the boost operation may be performed most efficiently.

Application Example 4

[0017] This application example is directed to the power generator according to the application example described above, which further includes a charging condition detection unit that detects a charging condition of the electrical storage device, wherein the control circuit performs control of short-circuiting the second switch and disconnecting the first switch when the charging condition detection unit detects a condition that the electrical storage device is not charged.

[0018] According to the configuration, when the boost operation is performed, if the charging condition detection unit does not detect charging, the boost operation is quitted and the second switch is connected. The state that the charging condition detection unit does not detect charging is a state in which no current flows from the piezoelectric member to the electrical storage device, and the boost operation in the state does not contribute to power generation. That is, the power necessary for the boost operation is wastefully consumed. Accordingly, if the charging condition detection unit does not detect any current, the boost operation is quitted so that the power may not be wastefully consumed. Further, if the boost operation is quitted, the generated voltage of the piezoelectric member is lower than that when the boost operation is performed because of the full-wave rectifier circuit only, and it becomes harder to flow a current from the piezoelectric member to the electrical storage device. However, if the second switch is short-circuited and the circuit is switched to the voltage doubler rectifier circuit, the output voltage of the piezoelectric member becomes larger than that of the full-wave rectifier circuit, and it is easier to supply the current to the electrical storage device. According to the configuration, the highly-efficient power generator may be provided.

Application Example 5

[0019] This application example is directed to a secondary cell including the above described power generator.

[0020] According to the configuration, even when the output voltage of the secondary cell is lower and the control of the first switch is impossible, the voltage doubler rectification is performed. Then, after the voltage equal to or more than the lower limit voltage necessary for driving the first switch is obtained, the operation is promptly shifted to the boost operation with high power generation efficiency, and thereby, the self-resettable secondary cell with higher power generation efficiency than that of normal full-wave rectification may be provided.

Application Example 6

[0021] This application example is directed to an electronic apparatus including the above described power generator.

[0022] According to the configuration, the electronic apparatus that may operate without replacement of a battery can be provided. Further, the secondary cell including the above described power generator may be provided in the electronic apparatus, and the electronic apparatus that may operate without replacement of the battery can be provided because the self-resettable secondary cell with higher power generation efficiency than that of normal full-wave rectification is provided.

Application Example 7

[0023] This application example is directed to a transporter including the above described power generator.

[0024] According to the configuration, the power generator of the application example of the invention is used for the transporter such as a vehicle or an electric train, and thereby, power may be generated by vibrations with the transportation and power may be efficiently supplied to an apparatus provided in the transporter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0026] FIG. **1** is a schematic diagram showing a structure of a power generator according to an embodiment.

[0027] FIGS. **2**A and **2**B are circuit diagrams of the power generator according to the embodiment.

[0028] FIGS. **3**A to **3**D are graphs showing an operation of the power generator in a stationary state according to the embodiment.

[0029] FIG. **4**A is a circuit diagram showing current paths when a second switch is short-circuited according to the embodiment, and FIG. **4**B is an equivalent circuit diagram of extraction of a part relating to the current flow paths in FIG. **4**A.

[0030] FIG. **5** is a flowchart for determination whether to perform an operation in the stationary state and an operation of obtaining a starting voltage according to the embodiment.

[0031] FIG. **6** is a circuit diagram of a secondary cell according to the embodiment.

[0032] FIG. **7** is a schematic view showing a schematic structure of a pedometer as an electronic apparatus according to the embodiment.

[0033] FIG. **8** is a circuit diagram for explanation of modified example 1.

[0034] FIGS. **9**A and **9**B show circuit diagrams for explanation of modified example 2.

[0035] FIG. **10** is a circuit diagram for explanation of modified example 3.

[0036] FIG. **11** is a circuit diagram for explanation of modified example 4.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Embodiment

Power Generator Including Configuration According to the Invention

[0037] As below, respective embodiments that embody the invention will be explained with reference to the drawings.

[0038] FIG. **1** is a schematic diagram showing a structure of a power generator according to the embodiment. A mechanical structure of a power generating unit **125** of a power generator **100** shown in the embodiment is a cantilever structure in which a beam **104** with a weight **106** provided on its end as a deforming unit is fixed to a support end **102** at the base end side. Further, a piezoelectric member **108** formed using a piezoelectric material such as lead zirconate titanate (PZT) is fixed and supported on the surface of the beam **104** as a supporter, and a first electrode **109***a* and a second electrode **109***b* as a pair of electrodes using conductors such as metal thin films are respectively provided on both sides of the piezoelectric member **108**. Note that, in the example shown in FIG. **1**, the piezoelectric member **108** is provided on the upper surface side of the beam **104**, however, the piezoelectric member **108** may be provided on the lower surface side of the beam **104** or the piezoelectric materials **108** may be provided on both the upper surface side and the lower surface side of the beam **104**. Note that "upper" refers to a direction as seen from the piezoelectric member **108** toward the first electrode **109***a* (a positive direction of u in the drawing), and "lower" refers to the opposite direction to "upper".

[0039] The beam **104** has the base end side fixed to the support end **102** and the weight **106** provided on the end side, and thus, when a vibration or the like is applied thereto, as shown by white arrows in the drawing, the end of the beam **104** largely vibrates. As a result, the piezoelectric member **108** attached to the surface of the beam **104** is subjected to cyclic deformation due to external force, and compression force and tension force alternately act thereon. Then, the piezoelectric member **108** generates positive and negative electric charge by the piezoelectric effect, and the electric charge appears in the first electrode **109***a* and the second electrode **109***b* and is extracted as a current.

[0040] FIGS. **2**A and **2**B are circuit diagrams of the power generator **100** according to the embodiment. The piezoelectric member **108** is electrically expressed as a current source I**0** and a capacitor C**0** for accumulation of electric charge. An inductor L is connected in parallel to the piezoelectric member **108** and forms an electrical resonator circuit with the capacitor component C**0** of the piezoelectric member **108**. Further, a first switch SW**1** for short-circuiting/opening the resonator circuit is connected in series with the inductor L. A second switch SW**2** is connected to the second electrode **109***b* and an electrical storage device C in FIG. **2**A, however, the second switch SW**2** may be connected to the first electrode **109***a* as shown in FIG. **2**B. Short-circuiting/opening of the first switch SW**1** and the short-circuiting/opening of the second switch SW**2** are controlled by a control circuit **110**. Further, the first electrode **109***a* and the second electrode **109***b* provided on the piezoelectric member **108** are connected to a full-wave rectifier circuit **120** including four diodes D**1** to D**4**. Though the details will be described later, to determine times to short-circuit the resonator circuit, a unit **140** configured to detect times at which the deformation directions are switched is provided. The embodiment determines the times at which the deformation direction is switched based on the current values flowing from the piezoelectric member **108** to the full-wave rectifier circuit **120**, however, the times may be determined using a displacement sensor or output voltages of the piezoelectric member. Here, junction diodes are used for the diodes D**1** to D**4**. The diodes D**1** to D**4** function as the full-wave rectifier circuit **120** when the second switch SW**2** is opened. Further, they function as a AC to DC converter that changes an alternating current into a direct current with the electrical storage device C.

[0041] Further, the diodes D**1** to D**4** function as a voltage doubler rectifier circuit **120***a* when the second switch SW**2** is short-circuited. The positive and negative electric charge generated by the piezoelectric member **108** is extracted by the first electrode **109***a* and the second electrode **109***b* as an alternating current. Then, the alternating current is converted into a pulsating current by the full-wave rectifier circuit **120** and the voltage doubler rectifier circuit **120***a* including the diodes D**1** to D**4**. Then, the pulsating current is charged in the electrical storage device C.

Operation in Stationary State

[0042] FIGS. **3**A to **3**D are graphs showing an operation of the power generator **100** in a stationary state according to the embodiment. Here, the stationary state refers to the case where a voltage that can control the operations of the first switch SW**1** and the second switch SW**2** is supplied to the control circuit **110**.

[0043] FIG. **3**A shows displacement of the end of the beam **104**. The longitudinal axis indicates displacement u and the lateral axis indicates time t. The unit of displacement is an arbitrary unit. As shown in FIG. **3**A, the displacement u of the end of the beam **104** changes with the vibration of the beam **104**. Note that the positive displacement u represents a state in which the beam **104** bends upward (the upper surface side of the beam **104** is concaved) and the negative displacement (−u) represents a state in which the beam **104** bends downward (the lower surface side of the beam **104** is concaved). Further, FIG. **3**B shows a current generated by the piezoelectric member **108** with the deformation of the beam **104** and an electromotive force generated inside of the piezoelectric member **108** as a result. Note that, in FIG. **3**B, generation of electric charge in the piezoelectric member **108** is expressed as an amount of electric charge (i.e., current Ip) generated per unit time. Here, a current Ipzt flowing in the piezoelectric member **108** is indicated by the longitudinal axis. Further, the electromotive force generated in the piezoelectric member **108** is represented with a potential difference Vpzt generated between the first electrode **109***a* and the second electrode **109***b* as the longitudinal axis. When the operation in the stationary state is performed, the second switch SW**2** is opened.

[0044] As shown in FIGS. **3**A and **3**B, while the displacement of the beam **104** increases, the piezoelectric member **108** generates a positive current (i.e., the current Ip takes a positive value). Accordingly, a potential difference Vp between the first electrode **109***a* and the second electrode **109***b* increases in the positive direction. If the positive potential difference Vp becomes larger than a sum of a voltage VC**1** between terminals of the electrical storage device C and double a forward voltage drop Vf of the diode forming the full-wave rectifier circuit **120**, i.e., VC**1**+2Vf, the electric charge to be subsequently generated may be extracted as a direct current and accumulated in the electrical storage device C. Further, while the displacement of the beam **104** decreases, the piezoelectric member **108** generates a negative current (i.e., the current Ip takes a negative value). Accordingly, the potential difference Vp between the first electrode **109***a* and the second electrode **109***b* increases in the negative direction. If the negative potential difference Vp becomes larger than the sum of VC**1** and 2Vf of the full-wave rectifier circuit **120**, the generated electric charge may be extracted as a direct current and accumulated in the electrical storage device C. This is a general power generation method. Here, a method of generating power more efficiently by controlling the first switch SW**1** will be explained.

[0045] FIG. **3**C is a graph showing times when the first switch SW**1** is short-circuited (ON), and the switch is turned on only in the times "ON". FIG. **3**D shows voltage waveforms obtained when the first switch SW**1** is short-circuited (ON) at the times shown in FIG. **3**C. The longitudinal axis indicates a potential difference Vgen generated between the first electrode **109***a* and the second electrode **109***b* as a generated voltage.

[0046] The first switch SW**1** is short-circuited (ON) at the times (times when the displacement of the piezoelectric member **108** becomes the local maximum or the local minimum) shown in FIG. **3**C. Then, as shown in FIG. **3**D, a phenomenon like that the voltage waveform between the first electrode **109***a* and the second electrode **109***b* sandwiching the piezoelectric member **108** shifts at the moment when the first switch SW**1** is short-circuited occurs. For example, in a period B shown by "B" in FIG. **3**D, the voltage waveform shown by a thick broken line like that the potential difference Vp shown by a thin broken line corresponding to the electromotive force of the piezoelectric member **108** shifts in the negative direction appears between the first electrode **109***a* and the second electrode **109***b* sandwiching the piezoelectric member **108**.

[0047] Further, in a period C shown by "C" in FIG. **3**D, the voltage waveform of a thick broken line like that the potential difference Vp corresponding to the electromotive force of the piezoelectric member **108** shifts in the positive direction appears. In the subsequent periods D, E, F, etc., similarly, the voltage waveforms of thick broken lines like that the potential difference Vp corresponding to the electromotive force of the piezoelectric member **108** shifts in the positive direction or the negative direction appear.

[0048] This is obtained using the resonance phenomenon in the resonator circuit including the inductor L and the capacity component C**0** of the piezoelectric member **108**. If the first switch SW**1** is short-circuited (ON) at the time when the displacement of the piezoelectric member **108** becomes the local minimum (when the displacement becomes −u in FIG. **3**A), the current flowing in the inductor L starts to gradually flow against the inductance of the inductor L. Then, the current flowing in the inductor L becomes the maximum when the voltage between the ends of the capacity component C**0** is zero. Then, the current continues to flow because of the inductance of the inductor L, and the current becomes zero when the voltage between the ends of the capacity component C**0** is inverted. Here, the first switch SW**1** is opened (OFF).

[0049] Then, the piezoelectric member **108** bends in the opposite direction. That is, the current Ip takes a positive value and charges the capacity component C**0** in the positive direction. As a result of the above described operation, the electric charge accumulated in the capacity component C**0** is held in the inverted state, and thus, when positive electric charge is newly add, the piezoelectric member **108** takes a larger value than the value that may be obtained in the general operation.

[0050] Then, the same operation is performed when the displacement of the piezoelectric member **108** becomes the local maximum (the displacement becomes u in FIG. **3**A), and thereby, in turn, a negative potential difference Vp having a larger absolute value than that of the value that may be generated in the general operation is generated. That is, the first switch SW**1** is short-circuited in a period of the half cycle of the resonance cycle of the resonator circuit including the capacity component C**0** and the inductor L at the times when the displacement of the piezoelectric member **108** is the local maximum or the local minimum, and thereby, power may be taken from the piezoelectric member **108** more efficiently.

[0051] In this case, the electric charge within the piezoelectric member **108** increases with deformation of the piezoelectric member **108** unless the electric charge is flown out from the piezoelectric member **108**. Accordingly, the voltage between the first electrode **109***a* and the second electrode **109***b* sandwiching the piezoelectric member **108** becomes larger.

[0052] Here, in the parts in which the voltage exceeds the sum of VC**1** and 2Vf (the parts shown by shading in FIG. **3**D), the electric charge generated in the piezoelectric member **108** is accumulated in the electrical storage device C. Accordingly, the electric charge flows out from the piezoelectric member **108** to the electrical storage device C, and the voltage between the first electrode **109***a* and the second electrode **109***b* sandwiching the piezoelectric member **108** is clipped at the voltage of sum of the voltage between terminals of the electrical storage device C and 2Vf (VC**1**+2Vf). As a result, the voltage waveform of the voltage between the first electrode **109***a* and the second electrode **109***b* is the waveform shown by a thick solid line in FIG. **3**D.

[0053] As clearly known from comparison between the case where the first switch SW**1** remains opened as shown in FIG. **3**B and the case where the first switch SW**1** is short-circuited at the times when the deformation direction of the beam **104** is switched, in the power generator **100** of the embodiment, electric charge may be efficiently accumulated in the electrical storage device C by short-circuiting/opening the first switch SW**1** at appropriate times.

[0054] Further, the electric charge is accumulated in the electrical storage device C and the voltage between terminals of the electrical storage device C increases, and accordingly, the amount of shift of the voltage waveform also increases. For example, in comparison between the period B in FIG. **3**D (the state in which no electric charge is accumulated in the electrical storage device C) and the period H in FIG. **3**D (the state in which electric charge is accumulated in the electrical storage device C), the amount of shift of the voltage waveform is larger in the period H. Similarly, in comparison between the period C and the period I in FIG. **3**D, the amount of shift of the voltage waveform is larger in the period I in which the electric charge accumulated in the electrical storage device C is larger. As a result, in the power generator **100** of the embodiment, the piezoelectric member **108** is deformed, and thereby, the voltage equal to or more than the potential difference Vp generated between the first electrode **109***a* and the second electrode **109***b* may be accumulated in the electrical storage device C. Consequently, it is no longer necessary to provide a special booster circuit, and the small and highly-efficient power generator may be obtained. Hereinafter, the operation is referred to as boost operation.

[0055] If the time when the control circuit **110** turns ON a switch SW and the time when the deformation direction of the beam **104** is switched do not exactly coincide with each other, the voltage Vgen between terminals of the piezoelectric member **108** may be boosted by turning ON the switch SW with a predetermined period in the time corresponding to the half of the resonance cycle of the resonator circuit including the capacity component C**0** of the piezoelectric member **108** and the inductor L.

[0056] Note that, the case where the time when the switch SW is turned ON and the time when the deformation direction of the beam **104** is switched coincide with each other is the most efficient, and the case where the time when the switch SW is turned OFF and the time when the deformation direction of the beam **104** is switched coincide with each other is the most inefficient. That is, the power generation efficiency is higher as the time when the switch SW is turned ON and the time when the deformation direction of the beam **104** is switched are as close to each other as possible.

Operation without Application of Starting Voltage

[0057] Returning to FIGS. **2**A and **2**B, in the case where the voltage at which the control circuit **110** may operate is supplied as the initial state through the above described boost operation, the power provided from the piezoelectric member **108** may be extracted with the higher efficiency than that in related art, however, in the case where the operation voltage (e.g., 3.3 V) is not provided to the control circuit **110** at the start time, it may be impossible to short-circuit/open the first switch SW**1** or perform the boost operation. Accordingly, it is necessary to temporarily accumulate the power for starting the control circuit **110**. For example, in consideration of application to a wristwatch, the piezoelectric member **108** is unable to generate power when the wristwatch is detached from the arm. Accordingly, when the energy accumulated in the electrical storage device C is exhausted, the control circuit **110** is difficult to be restarted and the power generator **100** is unable to start the boost operation. On this account, it is necessary to temporarily accumulate power required for restarting of the power generator **100**.

[0058] Here, when both the second switch SW**2** and the first switch SW**1** are opened, the voltage generated by the piezoelectric member **108** is subjected to full-wave rectification in the full-wave rectifier circuit **120** and applied to the control circuit **110**. The piezoelectric member **108** generates a voltage of about 2.5 V depending on the amplitude of the piezoelectric member **108**. The voltage is referred to as VC.

[0059] When rectification is performed using the full-wave rectifier circuit **120**, suppose that the forward voltage drop Vf is 0.4 V, the voltage after rectification takes a value expressed by the following equation. Note that, in the case of using the full-wave rectifier circuit **120**, the current passes through the diode twice, and the voltage twice as much as Vf is lost.

$$VC-2\times Vf=2.5\text{ V}-0.4\text{ V}\times 2=1.7\text{ V}$$

[0060] The voltage does not reach the voltage (e.g., 3.3 V) for starting the control circuit **110**, and it may be impossible to start the boost operation.

[0061] Accordingly, the second switch SW**2** is short-circuited and the circuit is operated as the voltage doubler rectifier circuit **120***a*, and thereby, the higher voltage than the starting voltage of the control circuit **110** may be charged in the electrical storage device C. The operation of charging the higher voltage than the starting voltage in the electrical storage device C will be explained using FIG. **4**A.

[0062] FIG. **4**A is a circuit diagram showing current paths when the second switch SW**2** is short-circuited according to the embodiment. Note that the description of the piezoelectric member **108** as the current source I**0** and the capacitor C**0** that accumulates electric charge is not so general illustration for the diagram of the voltage doubler rectifier circuit, and thus, the explanation will be continued with the piezoelectric member **108** as an equivalent circuit in which a voltage source V**0** and the capacitor C**0** that accumulates electric charge are series-connected. When the first electrode **109***a* side outputs a negative voltage and the second electrode **109***b* side outputs a positive voltage, a current flows along arrows of broken lines.

[0063] The current supplied from the voltage source V**0** passes through the second electrode **109***b*, then, passing through the diode D**2** and the first electrode **109***a*, charges the capacitor C**0**, and returns to the voltage source V**0**. When the first electrode **109***a* side outputs a positive voltage and the second electrode **109***b* side outputs a negative voltage, a current flows along arrows of solid lines. In this case, the voltage of the capacitor C**0** is added to the voltage from the voltage source V**0**, and they function as one voltage source. The voltage of the capacitor C**0** is obtained by subtraction of the voltage drop of the diode D**2** from the voltage VC of the piezoelectric member **108**. The current first passes through the capacitor C**0**, through the first electrode **109***a*, passes through the diode D**1**, and charges the electrical storage device C. Then, the current passes through the second electrode **109***b* and returns to the voltage source V**0**. Here, at charging of the electrical storage device C, the current is subjected to the voltage drop Vf of the diode D**1**, and the voltage between terminals of the electrical storage device C takes the following value.

$$(VC-Vf)+(VC-Vf)=(2.5-0.4)+(2.5-0.4)=4.2\ \text{V}$$

[0064] FIG. **4**B is an equivalent circuit diagram of extraction of a part relating to the current flow paths in FIG. **4**A. Specifically, FIG. **4**B is a circuit diagram of extraction of effectively functioning parts when the first switch SW**1** is opened and the second switch SW**2** is short-circuited. The circuit is a typical voltage doubler rectifier circuit and may supply a voltage nearly double VC as the voltage between the first electrode **109***a* and the second electrode **109***b* sandwiching the piezoelectric member **108** and charge the higher voltage than the starting voltage of the control circuit **110** in the electrical storage device C.

Operation Sequence

[0065] As below, an operation sequence of the power generator **100** will be explained.

[0066] FIG. **5** is a flowchart for determination whether to perform the operation in the stationary state or the operation of obtaining the starting voltage.

[0067] First, as step S**1**, whether or not the boost operation is enabled is determined. Specifically, whether or not a voltage equal to or more than the minimum starting voltage of the control circuit **110** is generated is determined.

[0068] If the voltage less than the minimum starting voltage is generated (step S**1**: N), the process moves to step S**5**.

[0069] At step S**5**, a boost operation start status is set to NG (boost operation disabled).

[0070] Then, as step S**6**, voltage doubler rectification is executed.

[0071] Then, as step S**4**, whether or not boost operation is enabled is determined.

[0072] If the voltage equal to or more than the minimum starting voltage is generated (step S**1**: Y), the process returns to step S**2**.

[0073] If the voltage less than the minimum starting voltage is generated (step S**1**: N), the process returns to step S**5**.

[0074] If the voltage less than the minimum starting voltage is generated at START time, the above described sequence is employed.

[0075] Then, if the voltage equal to or more than the minimum starting voltage is generated at START time, the following sequence is employed.

[0076] At step S**1**, if the voltage equal to or more than the minimum starting voltage is generated (step S**1**: Y), the process moves to step S**2**.

[0077] At step S**2**, the boost operation start status is set to OK (boost operation enabled).

[0078] Then, as step S**3**, the boost operation is executed.

[0079] Then, as step S**4**, whether or not the boost operation is enabled is determined.

[0080] If the voltage equal to or more than the minimum starting voltage is generated (step S**4**: Y), the process returns to step S**2**.

[0081] If the voltage less than the minimum starting voltage is generated (step S**4**: N), the process returns to step S**5**.

[0082] In this case, the operation sequence is operated with an infinite loop. Under the condition, it may be impossible to stop the operation. Accordingly, it is preferable to provide a function of stopping power generation, after waiting for an external Break signal at step S**4**, if the Break signal is received (step S**4**: with Break signal). Note that, for example, in the case of semi-permanent power generation, input processing of the Break signal may be omitted.

[0083] Note that the boost operation start status is changed, and thereby, control of waiting for the activation start until the status becomes OK, for example, or the like may be performed on a load (not shown) connected to the power generator **100**.

[0084] The above described power generator circuit exerts the following advantages.

[0085] As shown in FIGS. **3**A to **3**D, the resonance phenomenon in the resonator circuit including the inductor L and the capacity component C**0** of the piezoelectric member **108** is used, and thereby, the larger voltage than the voltage that the piezoelectric member **108** may generate alone as described above. Accordingly, power may be extracted from the piezoelectric member **108** more efficiently, and the small and highly-efficient power generator may be obtained.

[0086] As shown in "Operation in Stationary State", the electric charge within the piezoelectric member **108** increases with deformation of the piezoelectric member **108** unless the charge is flown out from the piezoelectric member **108**. Accordingly, the voltage between terminals of the piezoelectric member **108** becomes larger. If the loss when the electric charge flows through the inductor L and the first switch SW**1** or the like is not taken into account, the voltage between terminals of the piezoelectric member **108** is sequentially made larger. Therefore, with no special booster circuit, the voltage may be naturally boosted to the voltage necessary for driving of the electric load for power generation.

[0087] If the voltage between terminals of the electrical storage device C is once lower than the lower limit voltage that can drive the first switch SW**1**, it may be impossible to actively control the first switch SW**1** or perform the above described power generation operation, however, in this case, the operation of switching the control circuit **110** from the full-wave rectifier circuit **120** to the voltage doubler rectifier circuit **120***a* is performed. Accordingly, a voltage near twice the voltage in the piezoelectric member **108** is provided to the control circuit **110**. Through the voltage doubler rectification, the voltage between terminals of the electrical storage device C becomes higher than the lower limit voltage that can drive the first switch SW**1**, and the circuit is switched to the full-wave rectifier circuit **120** side and the control circuit **110** is operated in the above described rectification mechanism, and thereby, the self-resettable power generator **100** with higher power generation efficiency may be provided.

[0088] Switching from the full-wave rectifier circuit **120** to the voltage doubler rectifier circuit **120***a* may be performed by closing the second switch SW**2**, and thus, the self-resettable power generator **100** suppressed in increase in the number of parts with high power generation efficiency may be provided. In addition, if the voltage between terminals of the electrical storage device C keeps the voltage equal to or more than the lower limit voltage that can drive the first switch SW**1**, the full-wave rectifier circuit **120** is obtained only by opening the second switch SW**2**, and thus, power generation may be performed without reduction in power generation efficiency.

[0089] A normally-off switch is used as the first switch SW**1** and a normally-on switch is used as the second switch

SW**2**, and thereby, even if the voltage between terminals of the electrical storage device C does not reach the voltage that can control the operations of the first switch SW**1** and the second switch SW**2**, the second switch SW**2** is turned ON. That is, without control, the full-wave rectifier circuit **120** is switched to the voltage doubler rectifier circuit **120***a*, and thereby, the self-resettable power generator **100** with higher power generation efficiency may be provided.

Secondary Cell

[0090] As below, an example of forming the secondary cell will be explained.

[0091] FIG. **6** is a circuit diagram of a secondary cell according to the embodiment. A secondary cell **200** includes a power generator **101** and a voltage stabilizer circuit **130**. The power generator **101** has been described above, and the duplication of the explanation will be avoided.

[0092] The voltage stabilizer circuit **130** receives supply of power from the power generator **101** and supplies the power to a load (not shown). Here, the example using the power generator **101** has been explained, however, the power generator **100** may be used.

[0093] The above described secondary cell **200** exerts the following advantages.

[0094] Even when the voltage between terminals of the electrical storage device C is lower than the lower limit voltage that can drive the first switch SW**1**, if a vibration is applied once, the voltage doubler rectification is performed in the above described manner. Then, when the voltage reaches a voltage equal to or more than the lower limit voltage that can drive the first switch SW**1**, the operation is switched to the boost operation, and thereby, the voltage subjected to voltage adjustment and stabilized with respect to the load (not shown) by the voltage stabilizer circuit **130** may be efficiently provided.

Electronic Apparatus

[0095] As below, an example of an electronic apparatus will be explained.

[0096] FIG. **7** is a schematic view showing a schematic structure of a pedometer as an electronic apparatus according to the embodiment. A pedometer **1** includes a reset button **10**, a display part **11**, and a secondary cell **200**. When the pedometer **1** remains still in a long period, the voltage between terminals of the electrical storage device C (see FIG. **6**) of the secondary cell **200** is below the lower limit voltage that can drive the first switch SW**1**.

[0097] Here, when a vibration is once applied to the pedometer **1**, the secondary cell **200** performs the voltage doubler rectification as described above, the voltage between terminals of the electrical storage device C reaches the voltage equal to or more than the lower limit voltage that can drive the first switch SW**1**, then, the boost operation is promptly performed, and thereby, the pedometer **1** operates.

[0098] Note that, here, the pedometer **1** has been exemplified as the electronic apparatus, however, this is not limited to the pedometer, but may be applied to a wristwatch, wearable apparatus, or an electronic apparatus that is subjected to a mechanical vibration and operates, for example. Particularly, the boost operation is a rectification method with high efficiency, and may be preferably used for an electronic apparatus dealing with application having larger power consumption intended for wireless operation.

[0099] The above described electronic apparatus exerts the following advantages. The secondary cell **200** performs the boost operation with high power generation efficiency, and thus, may provide power with high efficiency even by a small vibration. Accordingly, a calculation function requiring power such as calorie calculation may be added as a function of the pedometer **1**, for example.

[0100] Further, the power generator of the embodiment of the invention generates power in response to vibrations and transportations, and thus, if the power generator is provided, for example, on bridges, buildings, or locations in which landslides are anticipated, power may be generated when a disaster such as an earthquake occurs and supplied to a network appliance such as an electronic apparatus only when necessary (when a disaster occurs).

[0101] Note that the power generator of the embodiment of the invention may be downsized and may be provided in various apparatuses including, but not limited to the electronic apparatus. For example, the power generator of the embodiment of the invention is used for a transportation means including vehicles and electric trains, and thereby, power may be generated by vibrations with the transportation and supplied to the apparatus of the transportation means with high efficiency.

[0102] Note that the invention is not limited to the above described embodiment, however, various changes, improvements, etc. may be made to the above described embodiment. Modified examples will be shown as below. Note that, for explanation of the modified examples, the same configurations as those of the above described embodiment have the same signs and their explanation will be omitted.

Modified Example 1

[0103] FIG. **8** is a circuit diagram for explanation of the modified example. As shown in FIG. **8**, an electrical storage voltage detection circuit **150** that detects a voltage between terminals of the electrical storage device may be provided between terminals of the electrical storage device C. The control circuit **110** performs control of performing the boost operation when the voltage between terminals of the electrical storage device C is higher than the lower limit voltage that can drive the first switch SW**1**, and opening the first switch SW**1** and short-circuiting the second switch SW**2** when the voltage is lower than the lower limit voltage that can drive the first switch SW**1**. Thereby, switching between the boost operation and the voltage doubler rectification is efficiently performed and the power generator with high power generation efficiency may be provided.

Modified Example 2

[0104] FIGS. **9**A and **9**B show circuit diagrams for explanation of the modified example. A charging condition detection unit **160** for determining whether or not a current flows from the piezoelectric member **108** to the full-wave rectifier circuit **120** is provided, and, if the charging condition detection unit **160** does not detect charging when the boost operation is performed, the control circuit **110** may stop the boost operation and short-circuit the second switch SW**2**. The state in which the charging condition detection unit **160** does not detect charging is a state in which no current flows from the piezoelectric member **108** to the electrical storage device C and the boost operation does not contribute to power generation. At this time, the boost operation is quitted, and thereby, the power for driving the first switch SW**1** may not be consumed wastefully.

[0105] Further, when the boost operation is quitted, normally, only the full-wave rectifier circuit **120** functions. Therefore, the generated voltage of the piezoelectric member **108** becomes lower than that when the boost operation is performed, and it becomes harder to flow a current from the piezoelectric member **108** to the electrical storage device C. However, when the second switch SW**2** is short-circuited and the circuit is switched to the voltage doubler rectifier circuit **120***a*, the output voltage of the piezoelectric member **108** becomes larger than that of the full-wave rectifier circuit **120**, and it is easier to supply the current to the electrical storage device C.

[0106] According to the configuration, the power generator with high power generation efficiency may be provided.

[0107] Note that the charging condition detection unit **160** may detect the current actually flowing from the piezoelectric member **108** to the full-wave rectifier circuit **120**. In this case, as shown in FIG. **9**A, the unit **140** configured to detect times at which deformation directions are switched in FIG. **2**A may substitute the unit. In addition, as shown in FIG. **9**B, the charging condition detection unit **160** may measure the voltages between anodes and cathodes of the diodes D**1**, D**3** of the full-wave rectifier circuit **120** and detect whether or not there is charging. In this case, if the voltage is higher at the anode side than that at the cathode side, a charging condition is determined such that a current flows from the piezoelectric member **108** to the electrical storage device C. The method is easily performed because it does not require measurement of a weak current flowing from the piezoelectric member.

Modified Example 3

[0108] The explanation will be made using FIGS. **4**A and **10**.

[0109] FIG. **10** is a circuit diagram for explanation of the modified example. In the modified examples 3, 4, the full-wave rectifier circuit **120** is formed using a schottky barrier diode. The schottky barrier diode has a property that its forward voltage drop is lower than that of a junction diode. Accordingly, a voltage higher by an amount of voltage corresponding to the difference in forward voltage drop between the junction diode and the schottky barrier diode may be supplied to the electrical storage device. However, there is a disadvantage that there is a large amount of backward leak current. When the circuit operates as the above described voltage doubler rectifier circuit **120***a*, the diode D**3** and the diode D**4** do not contribute to rectification (but there is no actual harm because the anode and the cathode are short-circuited with respect to the diode D**4**). The diode D**3** that does not contribute to voltage doubler rectification leaks a current and causes reduction in power generation efficiency. In this case, a joint diode is used only for the diode D**3**, and thereby, leak may be suppressed and the voltage may reach the voltage at which the control circuit **110** may promptly operate. FIG. **10** shows the circuit diagram when the diode D**3** is replaced by the junction diode.

Modified Example 4

[0110] The explanation will be made using FIGS. **4**A and **11**.

[0111] FIG. **11** is a circuit diagram for explanation of the modified example. When the circuit operates as the above described voltage doubler rectifier circuit **120***a*, the diode D**3** and the diode D**4** do not contribute to rectification (but there is no actual harm because the anode and the cathode are short-circuited with respect to the diode D**4**). That is, when voltage doubler rectification is performed, ideally, absence of them is advantageous. Accordingly, a normally-off MOS switch or the like is used in place of the diode **3**, and thereby, leak may be suppressed and the voltage may reach the voltage at which the control circuit **110** may promptly operate. Note that, after the control circuit **110** once operates, the MOS switch contributes to synchronously rectification, and thereby, full-wave rectification may be performed with suppressed forward voltage loss. FIG. **11** shows the circuit diagram when the diode D**3** is replaced by a switch SW**3**.

[0112] This application claims priority to Japanese Patent Application No. 2012-191468 filed on Aug. 31, 2012, the entirety of which is hereby incorporated by reference.

What is claimed is:

1. A power generator that generates power using power generated in a piezoelectric member when the piezoelectric member is deformed, comprising:

a deforming unit that repeatedly deforms the piezoelectric member;

a pair of electrodes provided on the piezoelectric member;

an inductor provided between the pair of electrodes and forming a resonator circuit with a capacity component of the piezoelectric member;

a first switch connected in series with respect to the inductor;

a unit that detects times when a deformation direction of the deforming unit is switched;

a full-wave rectifier circuit that rectifies a current output from the pair of electrodes;

an electrical storage device connected to the full-wave rectifier circuit and charging the current supplied from the full-wave rectifier circuit;

a second switch connected between one of the pair of electrodes and the electrical storage device; and

a control circuit that operates the first switch and the second switch.

2. The power generator according to claim **1**, wherein the control circuit disconnects the second switch and short-circuits the first switch when a voltage charged in the electrical storage device reaches a voltage that can drive the first switch.

3. The power generator according to claim **1**, wherein the control circuit performs control of disconnecting the second switch, and short-circuiting the first switch at the time when the deformation direction of the deforming unit is switched and, after a lapse of a time corresponding to a half-cycle of a resonance cycle of the resonator circuit, disconnecting the first switch when a voltage charged in the electrical storage device reaches a voltage that can drive the first switch and the second switch.

4. The power generator according to claim **1**, further comprising a charging condition detection unit that detects a charging condition of the electrical storage device,

wherein the control circuit performs control of short-circuiting the second switch and disconnecting the first switch when the charging condition detection unit detects a state in which the electrical storage device is not charged.

5. A power generator that generates power using power generated in a piezoelectric member when the piezoelectric member is deformed, comprising:

a deforming unit that repeatedly deforms the piezoelectric member;

a pair of electrodes provided on the piezoelectric member;

an inductor provided between the pair of electrodes and forming a resonator circuit with a capacity component of the piezoelectric member;

a first switch series-connected to the inductor;

a unit that detects times when a deformation direction of the deforming unit is switched;

a full-wave rectifier circuit that rectifies a current output from the pair of electrodes;

an electrical storage device connected to the full-wave rectifier circuit and charging the current supplied from the full-wave rectifier circuit;

a second switch connected between one of the pair of electrodes and the electrical storage device; and

a control circuit that operates the first switch and the second switch.

6. The power generator according to claim **1**, wherein the second switch is of a normally-on type.

7. The power generator according to claim **4**, wherein the control circuit performs control of disconnecting the second switch, and, after a lapse of a predetermined time from short-circuiting of the first switch at a time when the deformation direction of the deforming unit is switched, disconnecting the first switch when a voltage charged in the electrical storage device reaches a voltage that can drive the first switch and the second switch.

8. A secondary cell comprising the power generator according to claim **1**.

9. An electronic apparatus comprising the power generator according to claim **1**.

10. A transporter comprising the power generator according to claim **1**.

11. A secondary cell comprising the power generator according to claim **5**.

12. An electronic apparatus comprising the power generator according to claim **5**.

13. A transporter comprising the power generator according to claim **5**.

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